The G0 Experiment at Jefferson Lab

**G0**:   **Measurement of the Strange Quark Currents in the Proton**

G0 Collaboration:
Caltech, CMU, IPN-Orsay, ISN-Grenoble, JLab, LaTech, NMSU, TRIUMF, UIUC, U.Kentucky, U.Manitoba, U.Maryland, UNBC, Virginia Tech, William & Mary, Yerevan
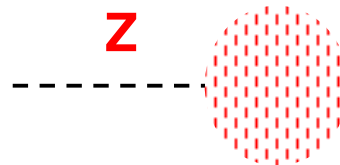
Measure G^p_Z : Weak form factor of the proton
- a *"new"* & *fundamental* property of the proton
- Weak interaction analogue of the usual EM form factors

G^p_γ : EM current distribution G^p_Z : weak current distribution
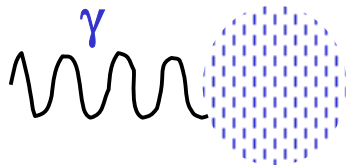
G^p_Z via parity-violating e-p scattering asymmetry

G^p_Z , G^p_γ $\Rightarrow$ $G^{p,s}$, Strangeness form factor of the proton

Weak "charge" & "magnetic" (Sachs) Form Factors

$$G_E \, , \, G_M \, \Longleftrightarrow \, F_1 \, , \, F_2$$

FORM FACTORS from PV ASYMMETRY

PV Asymmetry   **PROTON FORM FACTORS**

$$A(Q^2) = - \frac{(G_F Q^2)}{\pi \alpha \sqrt{2}} \left\{ \frac{\varepsilon G^\gamma_E G^Z_E + \tau G^\gamma_M G^Z_M + \eta G^\gamma_M G^Z_A}{\varepsilon (G^\gamma_E)^2 + \tau (G^\gamma_M)^2} \right\} \, [\, 1/P_Z \,]$$

(where ε , τ , η are kinematical parameters)

WANT TO EXTRACT G^Z_E and G^Z_M

DO 2 MEASUREMENTS OF $A(Q^2)$ *[Rosenbluth-like separation]*

For a given Q^2 , ε ranges from 0 (large angles) $\rightarrow$ **1** (small angles)

i) At large **(backward)** angles to determine G^Z_M

ii) At small **(forward)** angles to measure combination of G^Z_E and G^Z_M
   $\rightarrow$ extract G^Z_E

G0 MEASUREMENTS : 3 PHASES

A) Forward Angle Mode
B) Back Angle Mode
C) Deuterium Target Mode (Rad. Corr. to G^Z_A)

D) At Back-Angles, will also measure (concurrently) the N-Δ axial transition form factor

NUCLEON STRUCTURE and QUARKS

CURRENTS:

$$G^{\gamma p}_{E,M} \rightarrow \Sigma\, Q_j \langle p| q_j \gamma^\mu q_j |p\rangle$$

$$G^{Z p}_{E,M} \rightarrow \Sigma\, (\tfrac{1}{2}T^3_j - Q_j \sin^2\theta_W)\, \langle p| q_j \gamma^\mu q_j |p\rangle$$

EW Nucleon Form Factors $\rightarrow$ Written as sum of contrib. from each flavour (neglect heavy quarks c,t,b)

$$G^{\gamma p}_{E,M} = (1/3)\,[2G^{u,p}_{E,M} - G^{d,p}_{E,M} - G^{s,p}_{E,M}]$$

$$G^{Z p}_{E,M} = (\tfrac{1}{4} - \tfrac{2}{3}\sin^2\theta_W)G^{u,p}_{E,M} - (\tfrac{1}{4} - \tfrac{1}{3}\sin^2\theta_W)G^{d,p}_{E,M}$$
$$- (\tfrac{1}{4} - \tfrac{1}{3}\sin^2\theta_W)G^{s,p}_{E,M}$$

$$G^{\gamma n}_{E,M} = (1/3)\,[\,2G^{u,n}_{E,M} - G^{d,n}_{E,M} - G^{s,n}_{E,M}\,]$$

$$\Downarrow$$

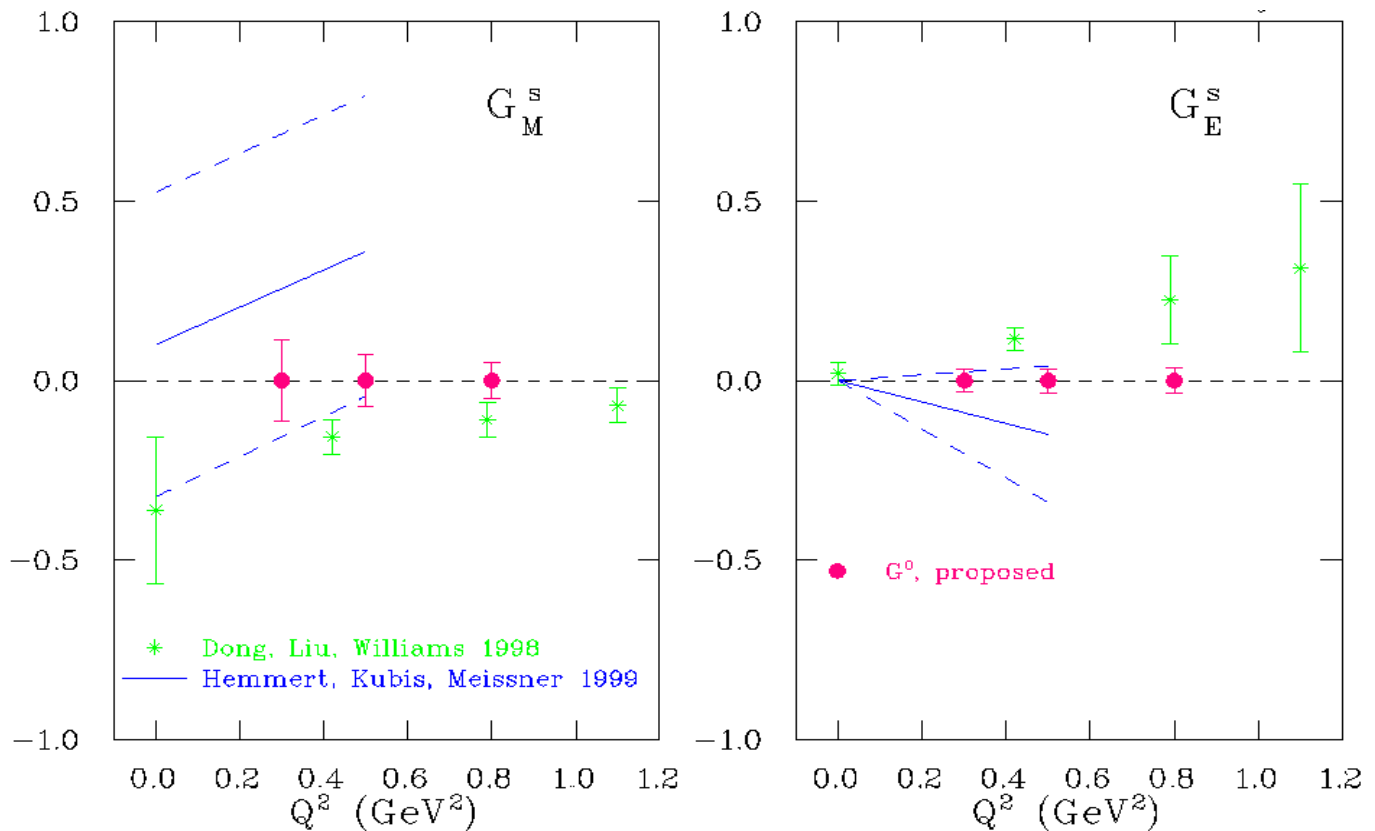**ASSUMING ISOSPIN SYMMETRY
OF THE PROTON AND NEUTRON**

$$\Downarrow$$

$$G^{u,p}_{E,M} = (3 - 4\sin^2\theta_W)G^{\gamma p}_{E,M} - 4G^{Z p}_{E,M}$$

$$G^{d,p}_{E,M} = (2 - 4\sin^2\theta_W)G^{\gamma p}_{E,M} + G^{\gamma n}_{E,M} - 4G^{Z p}_{E,M}$$

$$\boxed{G^{s,p}_{E,M} = (1 - 4\sin^2\theta_W)G^{\gamma p}_{E,M} - G^{\gamma n}_{E,M} - 4G^{Z p}_{E,M}}$$

THEORETICAL ESTIMATES & EXPECTED ERRORS for G0

Related Measurements

HAPPEX $(G^S_E + 0.39 G^S_M)$ at $Q^2 = 0.47$ (GeV/c)^2
    consistent with zero

SAMPLE G^S_M at $Q^2 = 0.1$ (GeV/c)^2

Recently (prelim)

PVA4 at Mainz $(G^S_E + 0.21 G^S_M)$:	$Q^2 = 0.23$ (GeV/c)^2
SAMPLE 2001 $(D_2$ Tgt):	$Q^2 = 0.03$ (GeV/c)^2
HAPPEX:	$Q^2 = 0.1$ (GeV/c)^2

G0 Schematic Layout and Experiment Parameters

Detectors

Contours of constant Q^2

Superconducting Coils

Electron Beam
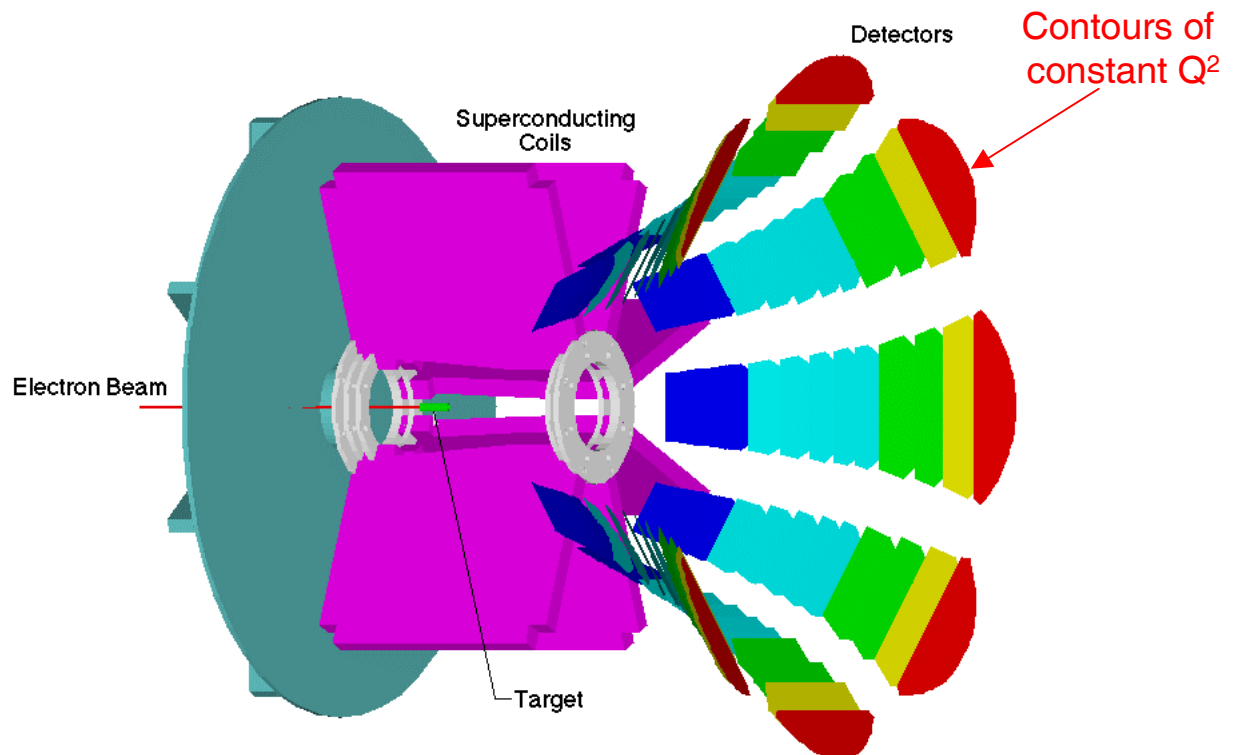
Target

Measure Scatt.Asymmetry, A_z for e^- ($\Rightarrow$ and $\Leftarrow$) on p

Goal: Measure $A_z \sim 5 \times 10^{-6}$ to $(\Delta A/A) \sim \pm 5\ \%$ (10^{-7})
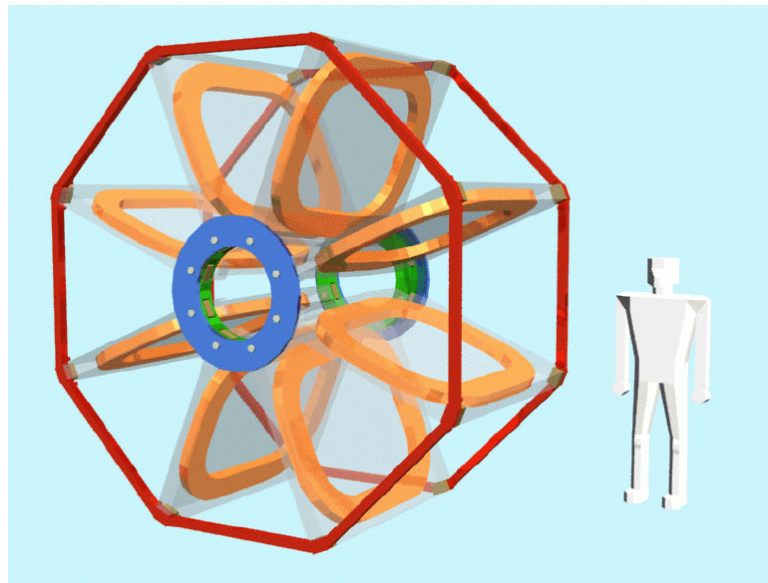
Experiment Parameters:

Beam Structure	31.25 MHz (32 ns)
Beam Current	40 μA
Polarization	70 %
Energy	0.3 – 3 GeV
Target	20 cm LH$_2$

Systematics: (h.c. variables)

ΔE	$< 2.5 \times 10^{-8}$	
$\Delta Q/Q$	< 1 ppm	over 30 days
Δx	< 20 nm	
$\Delta\theta$	< 2 nrad	

Superconducting Toroidal Magnet

8-Sector
R ~ 2m, L ~ 2m
Iron-free
T_O ~ 4.5 K
$\Delta\Omega$ ~ 0.5–0.9 sr

(forward mode)
I_O ~ 5 kA
B_ϕ ~ 1.7 T

Liquid Hydrogen Target
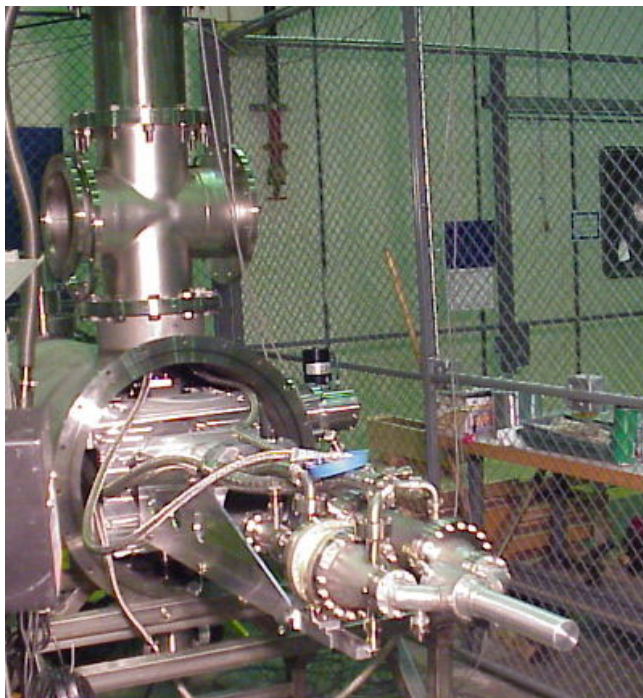
20 cm LH_2 cell

250 W heat load from beam

High circulation rate to minimize target density fluctuations

Forward Angle Configuration
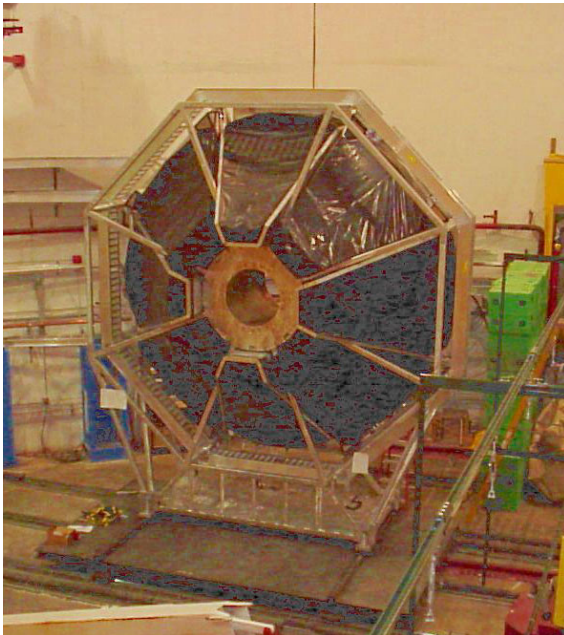
Focal Plane Detectors (Single Sector)

North American FPD octant

French FPD octant

FPDs (8 Sectors)

FPDs on ferris-wheel support

Scintillators
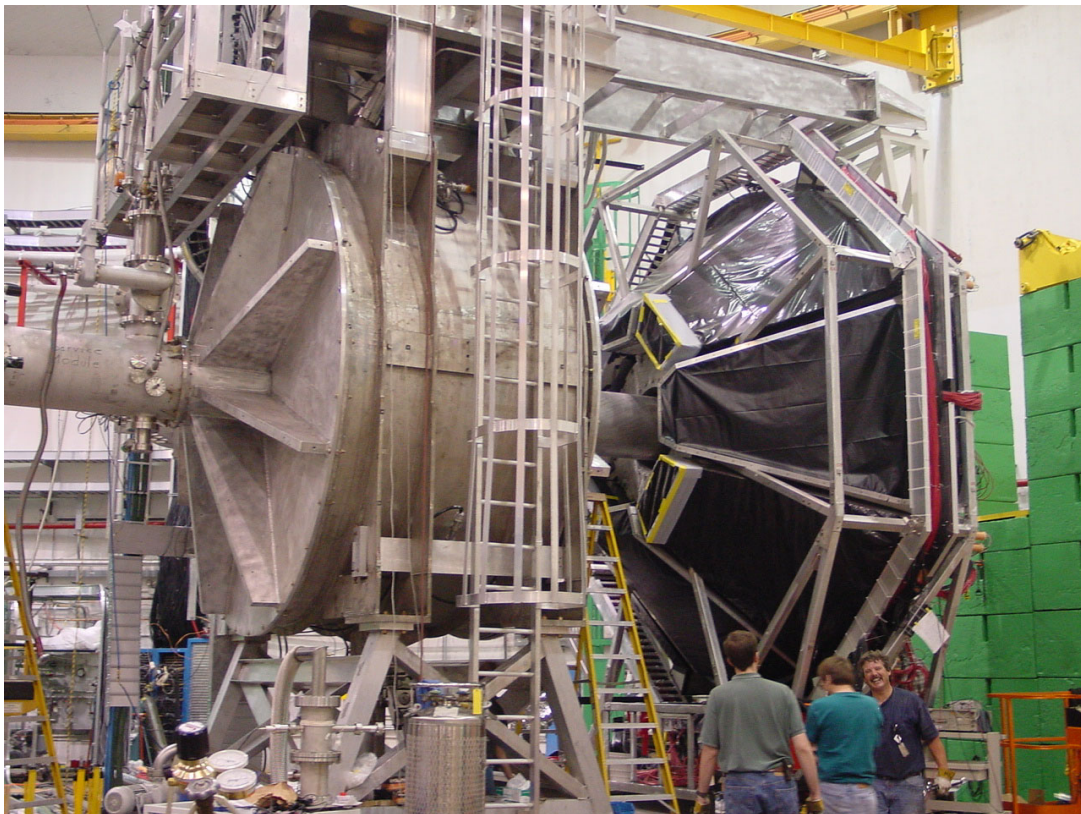→ Shape: Q^2 Contours
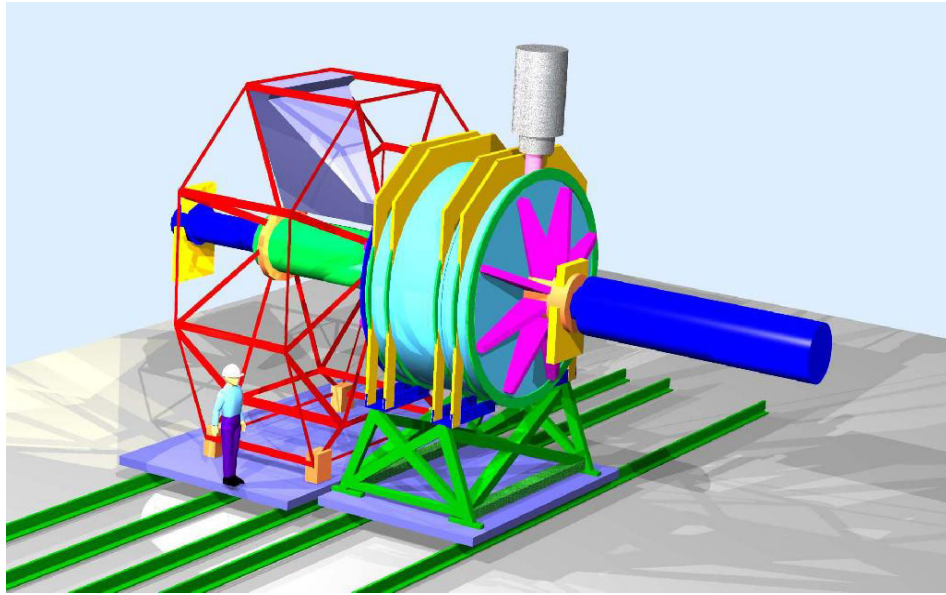→ Segmentation: R < 1 MHz
LightGuides
→ Long guides w/ helical bends

Electronics/DAQ
32 ns between beam pulses
TOF to select elastics
→NA: MT ➔ LTDs ➔ Scalers
   ("Scalers" TOF spectra, 1 ns)
→Fr: MT ➔ Flash TDCs
                (0.25 ns)
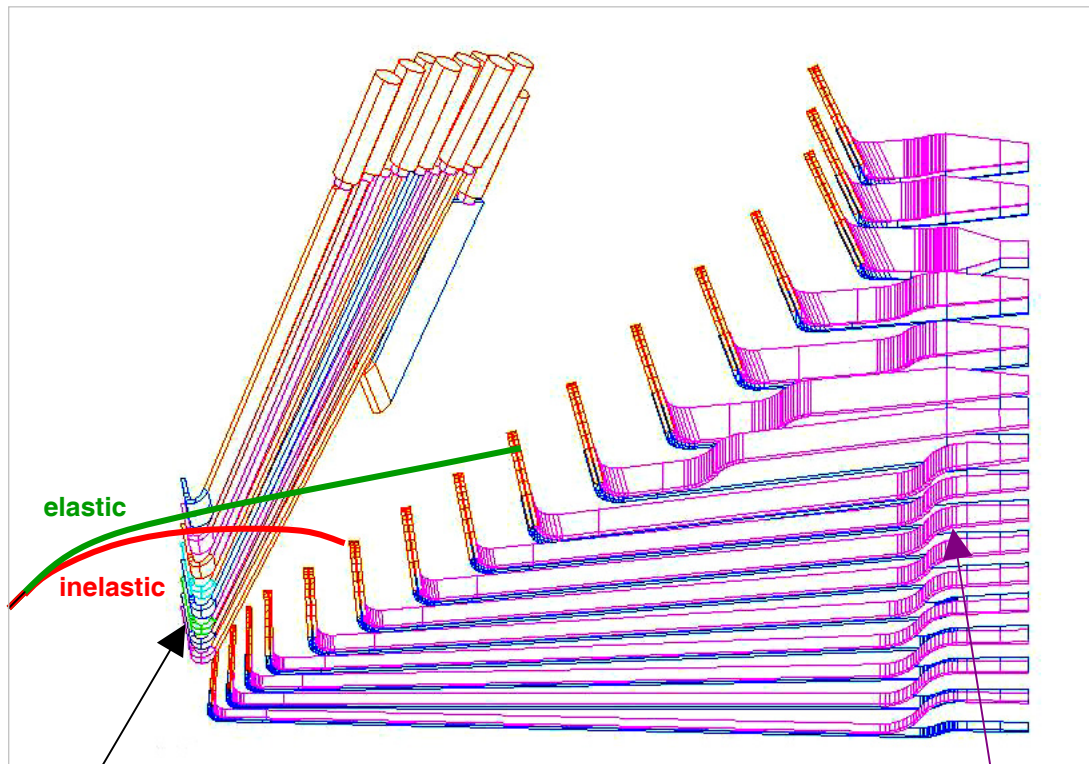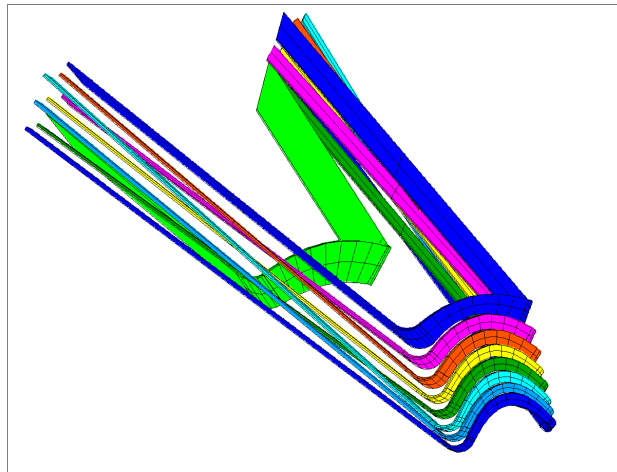
Forward Angle Configuration

G0 Target-Magnet-FPD in Hall C

Back-Angle Configuration (Hydrogen Target)

Magnet & Detector Package turned around

Measure back-scattered electrons

- Require additional det.^{s}
  Cryostat-Exit Detectors
  (CEDs)

- CED-FPD coincidence
  used to separate elastic
  & inelastic electrons
- Inelastics
  (N-Δ axial transition FF)
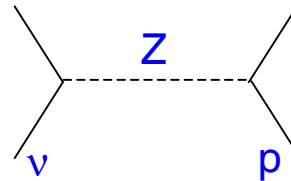

elastic

inelastic

CEDs (Cryostat Exit Detectors)

FPDs

Axial Form Factor of the Proton

PV Asymmetry : $A(Q^2) \propto \varepsilon G^\gamma_E \mathbf{G^Z_E} + \tau G^\gamma_M \mathbf{G^Z_M} + \eta G^\gamma_M \mathbf{G^Z_A}$

Extract $\mathbf{G^Z_E}$ and $\mathbf{G^Z_M}$; G^γ_E and G^γ_M known ;
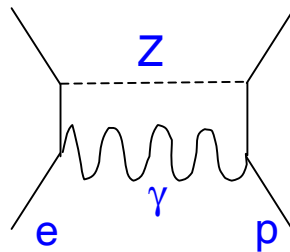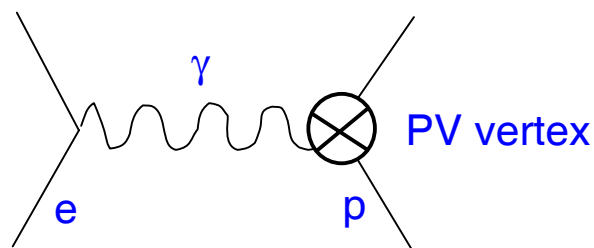
$\mathbf{G^Z_A}$ from ν-p scattering, but…

In e-p scattering, there are radiative corrections:

$$\mathbf{G^Z_A} \rightarrow \mathbf{G^e_A} = \mathbf{G^Z_A} + R^e + \eta \mathbf{F_A}$$

(a) "Standard" radiative corrections, R^e

(b) Additional diagrams with $Z^0/W^\pm$ exchange between quarks

PV vertex

(more complicated calculation)

An "effective" axial (PV) coupling of the photon to the nucleon,
identified as: $\mathbf{F_A}$, the *Anapole Moment* of the nucleon
(Zel'dovich, '57)

Effective Axial Form Factor

Radiative corrections: $G^Z_A \rightarrow G^e_A = G^Z_A + R^e + \eta F_A$

Option:
Compute radiative correction terms, F_A.
Musolf & Holstein (90): Low energy eff. theories of Hadronic Weak Int.
Weak meson-nucleon couplings **(DDH param.^{s}: h_ρ, f_π)**
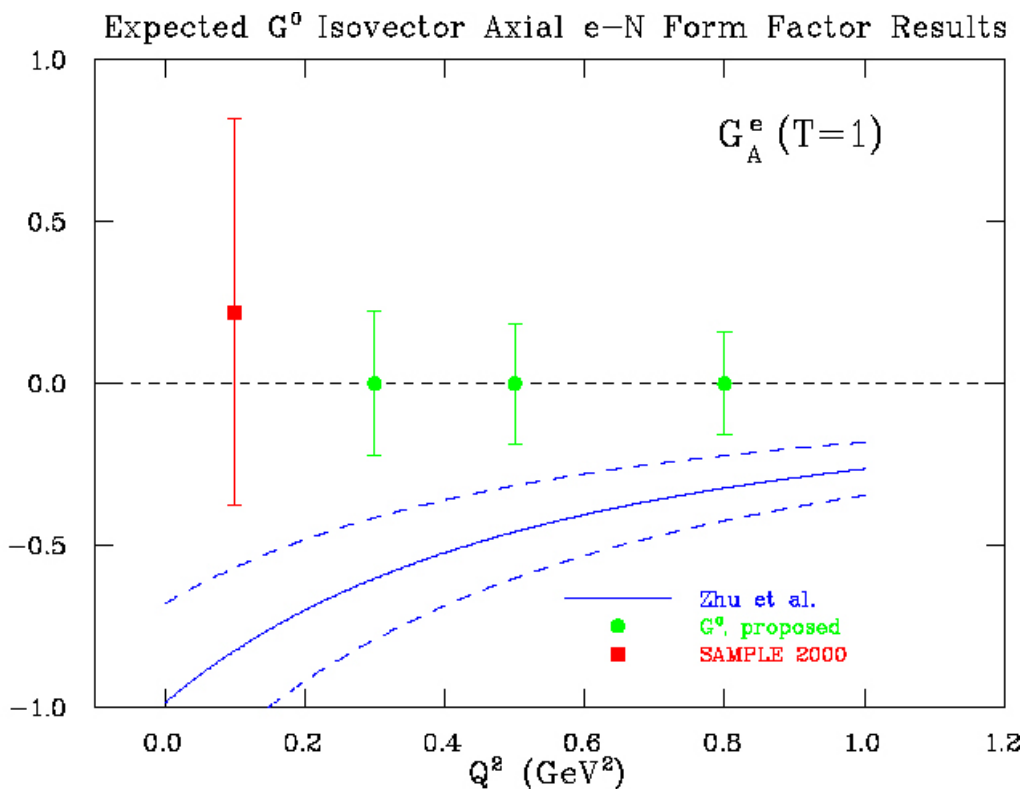Large Uncertainties

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Alternate Option:

Deuterium quasielastic scattering at back-angles is more sensitive to G^e_A than to G^S_M $\rightarrow$ eg., at $Q^2 \sim 0.1$ GeV^2

$$A^{ed} \sim Q^2 (1 + 0.22\, G^e_A - 0.10\, G^S_M)$$

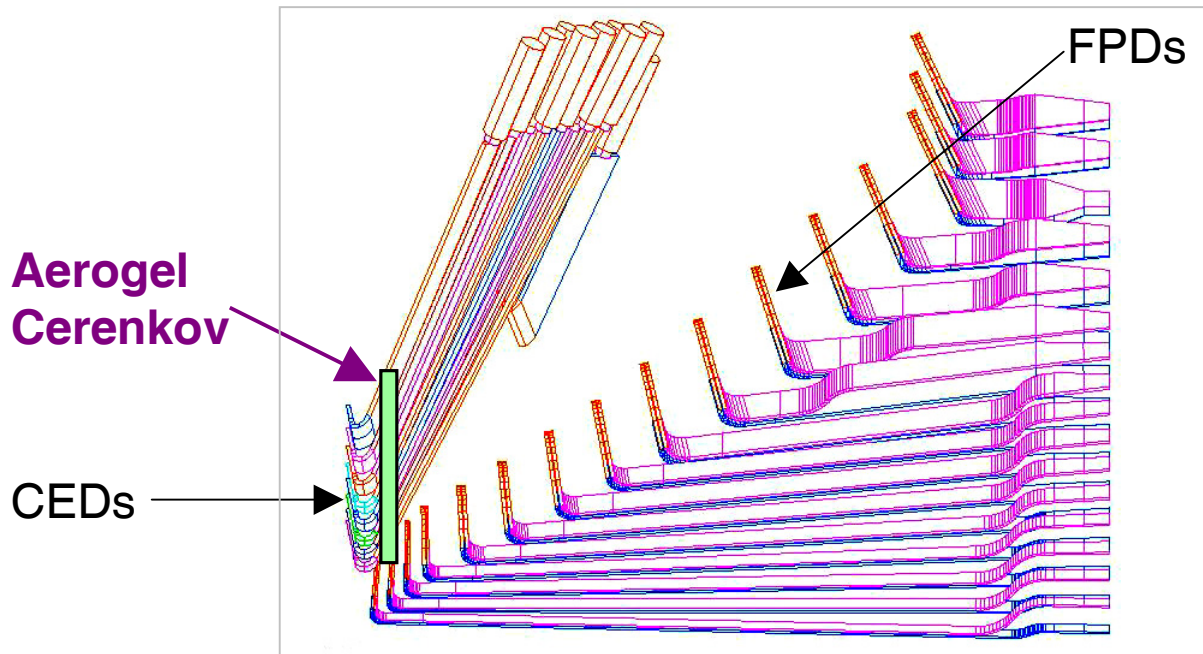$$\text{vs} \quad A^{ep} \sim Q^2 (1 + 0.24\, G^e_A - 0.61\, G^S_M)$$

Extraction of G^e_A with Deuterium Target

Expected G^0 Isovector Axial e–N Form Factor Results

$G^e_A (T=1)$

Zhu et al.
G^0, proposed
SAMPLE 2000

Back-Angle Configuration (Deuterium Target)

Pion Backgrounds: (FPD, CED) *plus* Cerenkov Arrays
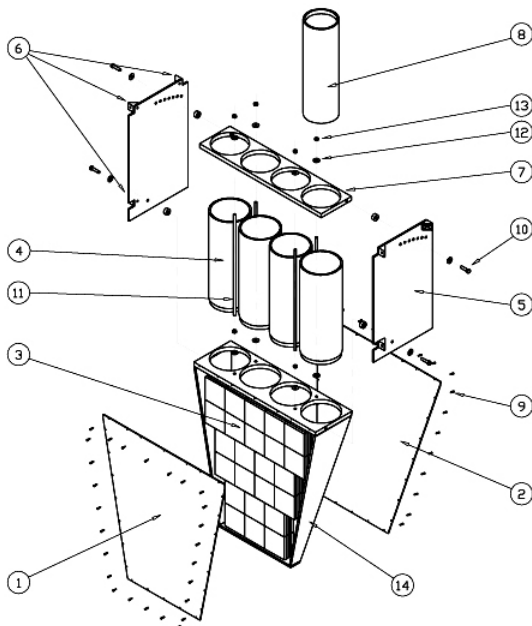

FPDs

Aerogel Cerenkov

CEDs

Back-scattered electron :
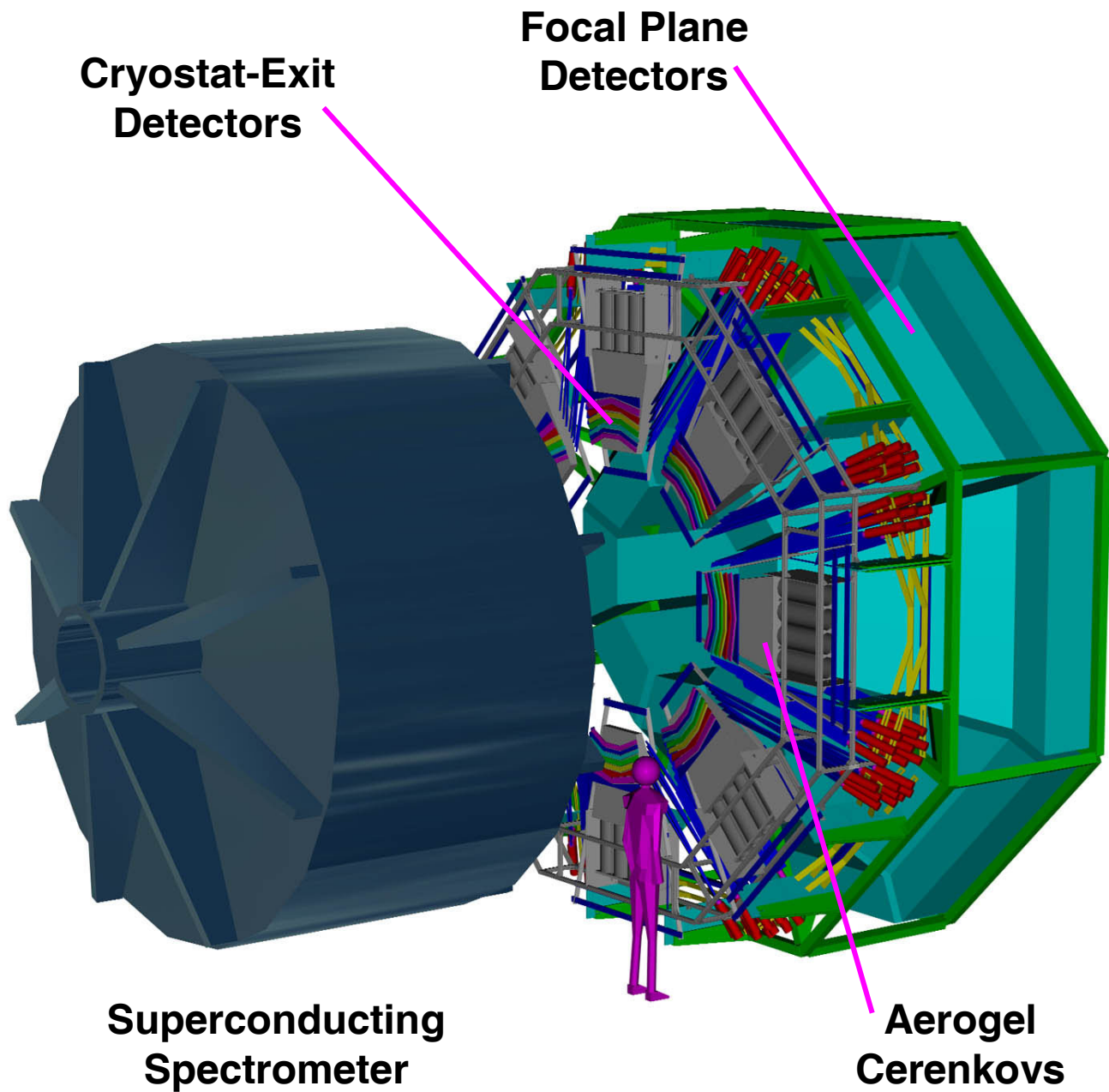CED-FPD coinc. separates elastic & inelastic e^- 's

Background pions from π-production off D_2 & Al :
Cerenkov for π^- /e^- separation (n ~ 1.03)

Prototype Aerogel Cerenkov:

G0 Back-Angle Configuration

Cryostat-Exit Detectors

Focal Plane Detectors

Superconducting Spectrometer

Aerogel Cerenkovs

Status of G0 Experiment

Forward Angle Mode:
Construction Completed
Commissioning Phase

Backward Angle Mode:
Additional Detectors being fabricated

Schedule:

1st Commissioning Run (Non-physics)	Aug, Sep 2002
2nd Commissioning & Physics Runs	Fall 2002
	2003
"Turn around" to Back-Angles & Physics Run	2004
[1st Q^2 point (0.8 Gev^2)]	
Physics Run	2005
[2nd and 3rd Q^2 points]	

G0 Aug/2002 Commissioning Run

G0 Beam:

Laser(s) ➔ 31 MHz beam delivered

Beam Current ~ 10 μA

Beam sizes ➔ initially large σ ~ 1-2 mm,

➔ eventually σ ~ 0.22 mm

Exercised helicity-control devices

Measurements w/ Beam monitors

Magnet & Target:

Magnet cold, not energized [Sep/2002]

Target installed, not used (solid target)

Detectors & DAQ:

FPDs turned on

Backgrounds studied, Rates measured

Fastbus/Diagnostic events obtained

Some Time-Encoding data obtained

SUMMARY

1) G0 will contribute to the measurement of a "new" and
   fundamental property of the proton
   (G^p_Z : weak current distribution of the proton).

2) Measurement of G^p_Z enables decomposition of the proton
   ground state matrix elements into quark contributions
   (G^{pu} , G^{pd} , and **G^{ps} -- strange quark current distribution;
   a direct measurement of the quark sea**).

3) The physics is of great current interest and high priority.
   Questions related to $s\bar{s}$ pairs in nucleon: contributions to
   E-J sum rule, and to πN sigma term.
   $G^{ps} \rightarrow$ definitive statement about $s\bar{s}$ pairs.

4) With additional measurements on deuterium, G0 will also
   be able to make a statement about the **anapole moment**
   of the proton.